NASA TECHNICAL TRANSLATION NASA TT F-15,278

A ROBOT ON THE LADDER OF EVOLUTION

M. Vasin

(NASA-TT-F-15278) A ROBOT ON THE LADDER OF EVOLUTION (Kanner (Leo) Associates) 24 p HC $3.25 CSCL 05H

N74-15134

Unclas
G3/15 27509

Translation of "Robot pered lestintsey evolyutsii," Nauka i Zhizn', No. 11, November 1973, pp. 16-25

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JANUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,278	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A ROBOT ON THE LADDER OF EVOLUTION		5. Report Date January 1974 6. Performing Organization Code
7. Author(s) M. Vasin		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw-2481 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Robot pered lestintsey evolyutsii," Nauka i Zhizn', No. 11, November 1973, pp. 16-25

16. Abstract Two robots developed and constructed at the Leningrad Institute of Aviation Instrument Design are described. They are a six-legged walking "spider" and a four-eyed manipulator arm. At this stage of development, the robot-manipulators created at the institute are being assembled from parts already produced by industry but used in aviation technology. The spider can travel across almost any terrain by varying its gait and posture; the fastest gait is three legs at a time (6 km/hr). It can even stand "on tiptoe" or crouch and, with special attachments, can travel along precipices and slopes. Its laser eye can see for 10-15 m and simultaneously measre distances with an accuracy of 5 mm. The other, simpler, robot is a manipulator arm with four photocell "eyes" and a working surface with tactile sensors which, in addition to sensing the object, also determines the angles at which the various elements of the hand are located and the effortrequired by the hydraulic "muscles."

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified-Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 23	22. Price

ROBOT ON THE LADDER OF EVOLUTION
(Report from the Leningrad Institute of Aviation Instrument-Building)

M. Vasin

Constructing robots and manipulators called on to service /16* both scientific research and production processes has in recent years become one of the significant directions in scientific and technical progress. In particular, it serves the goals of the broad automatization of manufacturing processes without which building the material and technical base of communism is inconceivable. It is revealing that in recent years a new term -- robotization -- has even begun to be used. Essentially, it is one of the higher forms of manufacturing automatization.

Teams of scientists, engineers, and designers in the most varied fields of technology are working on building robots. A special commission (on the theory and principles of the construction of robots and manipulators) headed by Academician I. I. Avtobolevskiy, was set up to coordinate these efforts and to determine the most important directions of research in the USSR Academy of Sciences.

This article deals with interesting and vital work underway on the construction of robots and manipulators at the Leningrad Institute of Aviation Instrument-Building.

Synthetic Machine

An aviation-oriented higher educational establishment is building robots? Is this actually urgent? And is there really

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* Numbers in the margin indicate pagination in the foreign text.

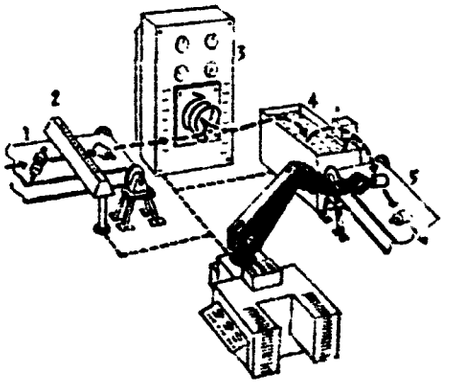
anything common shared by robots and aircraft? Perhaps, you want to set up the production of iron stewardesses and think that the passengers will thank you for it?

Such questions are often put to specialists at the Leningrad Institute of Aviation Instrument-Building. In replying to them, the rector of the educational center, A. A. Kapustin first tries to quiet the potential passengers: no, no, there are absolutely no plans to replace our sympathetic, affable, and solicitous stewardesses with any kind of metal replica of man. But thinking /17 and agile automata of course are necessary both in aviation and in many other sectors of the national economy. Incidentally, the most primitive robots have long since been found as part of the air fleet, all one needs to recall is the device called the autopilot.

The areas in which human labor is usefully replaced by machine labor are quite numerous. Let us say, why could not robot-manipulators sort baggage at airports, load and unload aircraft, and perform labor operations at conveyors and machine tools in aircraft and other kinds of plants? Unfortunately, thus far there are very few such automatic helpers of people.

Still, an entire host of them is ready to appear on the scene. And more than that, it can be stated that some kinds of robots have already been born. But they have been born by parts, and these parts are living and functioning independently of each other.

In various fields of endeavor elements from which robots are actually constructed have long since been developed and are being used for specific applications: the electronic brain; transducers from which data is fed to an electronic computer (EC); hydraulic, pneumatic, and electric motors capable of acting as muscles; structures that could be used as hands and legs of an intelligent



Scheme of one of the possible variants for robot-manipulator servicing of a production section for surface hardening of parts using high-frequency currents. In the center is a mechanical arm with a computing device that is connected by cable (shown by dashed line) with all the equipment and which controls it. The parts arrive along conveyor 1 and pass under the photoelectric "ruler" 2 which recognizes their configuration and their position on the travelling tape. The parts are seized by the robot arm and are placed in the induction furnace 3; after being heated, the robot transfers them into the hardening oil bath 4, and from there onto the finished-product conveyor 5.

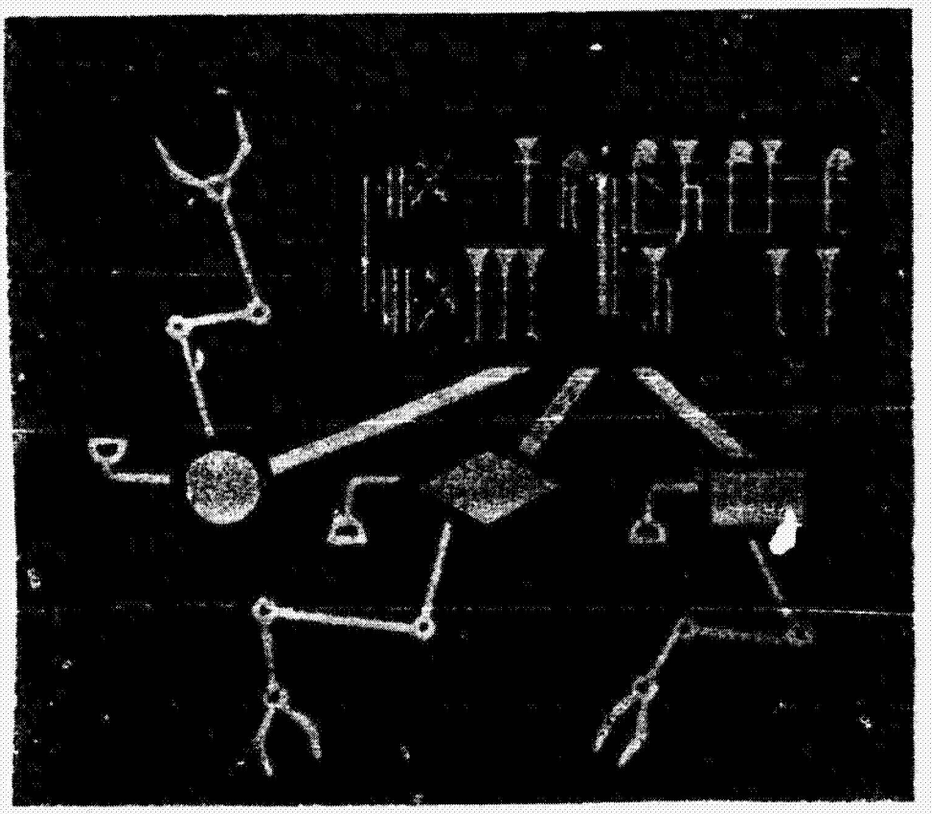
Another feature of this period in the view of A. A. Kapustin, is that today the problems of building robots are being pursued in higher educational centers also on a synthetic basis, where specialists of the most diverse fields are assembled and where the many years of experience of famous scientists and the energy of youth, broad knowledge and fresh views at established scientific concepts are being combined. /18

For already 5 years now in the Leningrad Institute of Aviation Instrument-Building dozens of graduate students and upperclassmen have worked on these new problems in various faculties along with professors. Some of them are working in the robot design group, others -- in the group of developers of data transducers, and still others in the group investigating problems of controlling manipulators using electronic computers.

Four-Eyed Arm

A door bearing the plate "Laboratory of Robots," on admitting us, closes shut. In the center of the room, amidst racks containing instruments, funicular polygons, and modules of an

automaton. Therefore, one need only adapt one element to another, collect all into one entity in order to produce a robot-manipulator -- a synthetic machine uniting the advances in many fields of science and technology. Incidentally, manipulators built at the Leningrad Institute of Aviation Instrument-Building have been constructed mainly of parts, instruments and devices produced by out industry on a series-manufacturing basis and utilized in helicopters, aircraft and other flight craft.



Music of labor. This symbol (artist G. L. Popov) is placed on the cover of the book Algoritmy upravleniya robotami-manipulyatorami, [Control Algorithms of Robot-Manipulators]

The present period in robot construction can be called the period of the synthesis of intelligent machines from ready (or nearly ready) parts.

electronic computer, stands an enormous, Dural spider with long legs, barely bent at the joints, planted in alert pose. Its six-cornered trunk terminating in some kinds of tubing, hoses, conductors and instruments (I was later told that this "brain" of the spider is a computer, and that its "heart" and "muscles" are hydraulic drives) rises nearly a meter from the floor. Beyond the spider, against the wall could be seen a powerful metallic arm raised upward as if greeting the visitors with its massive wrist-claw.

"These are our functioning robots. But to demonstrate all that they are capable of doing in a laboratory is hard. One will have to imagine," states the head of the computer faculty of the Leningrad Institute of Aviation Instrument-Building, Professor, M. B. Ignat'yev. "Imagine, for example, that we are now in one of the shops of a turbine blade plant. And now in front of us is not a rack containing parts, but a heat-treatment furnace loaded with parts. The parts have already been heated to the required temperature (1000° and higher). A worker lifts them from the furnace and lowers them into an oil bath. Heat, smoke. The work is fatiguing and monotonous, therefore uninteresting.

So why could not an automaton be built that would replace the worker at the furnace and the oil bath? It is not easy to construct such an automaton. It turns out that underlying the most elementary actions -- to pick up some object and to transfer it to another location -- is quite a complicated intellectual process. The automaton must first of all see and recognize the object, secondly, determine where and how it should best be seized, and third -- bring its arm precisely to this location, and then sense contact with the part and only thereafter compress the claw or, as we call it, the grab. Then follow also very difficult tasks: to cautiously extricate a part from the furnace without brushing en route another item of equipment or obstracle, and to accurately

lower the load into the oil bath. This is completely beyond the ability of a traditional automaton. Here one needs a "thinking" automaton-manipulator controlled with an electronic computer, that is, a robot. It is precisely this device that has been built by a team at our faculty, in particular, the group for the design of robots to automate manual and auxiliary work, headed by principal designer A. A. Mikhaylov.

"And now imagine that instead of a worker at the furnace stand a robot -- a mechanical arm," continues Professor M. B. Ignat'yev. "The program for his actions has been placed in the controlling computer. One need only give the command to begin operation..."

The robot begins to stir, stretches out its claw-grip into the furnace opening, feels for the incandescent part, grips it precisely in the middle, extracts it cautiously, carries it -- bypassing nearby objects -- to the bath and lowers it into the oil. It returns for a second part, then for a third, a fourth, ... and so without fatigue, without respite. It was not troubled if in the furnace it discovered parts with different shapes or different weights (this is an insoluble problem for an ordinary, mechanical automaton): data on the possible changes in working /19
conditions are placed in the robot memory, that is, in the electronic computer, and it flexibly modifies its behavior and passes from one form of activity to another.

It has all the capabilities to do this. In its claw are housed four photo-eyes with which the robots sees a part at either distance or in direct proximity. The working surfaces of the claw-grab have tactile organs -- tactile transducers. The joints sense both the angles of rotation of the various arm components (and it has a total of seven degrees of freedom) and the forces that must be applied to the hydraulic muscles during operation. In order to make it clear how complicated and sensitive

this mechanical arm is, it is sufficient to state that signals from 80 different transducers are continuously fed into the electronic computer and processed there.

But even such a data flow proves limited for the reliable and trouble-free performance of the robot. Today scientists and designers at the institute wish to clothe the metal arm with a special "skin," which like human skin will inform the brain about contact of the arm with objects. This is necessary for the safety of both the robot itself and of everything that is around it, people, equipment and structures.

"A robot, like a motor vehicle, is an object of increased risk," explains designer engineer M. M. Zakharov. "Of course, the production personnel that will deal with robots must necessarily study the safety regulations, rules of behavior and handling of these helpers of theirs. But greater guarantee of safety necessitates that the robot itself be more cautious, that so to speak discretion be coded into its behavior program. I recall, for example, the following incident. We had just begun working with the automatic arm. Suddenly, the control malfunctions. We rush to it in order that it not harm itself, we wish to stop it, to hold it down. But the arm flung me and banged against the wall..."

Ruler Recognizes Images

The mechanical arm is capable of mastering many occupations: welder, painter, sandblaster, stevedore.... It can drill holes, tighten nuts. A low-capacity electronic computer is fully capable of controlling it.

Obviously, it is simplest to use such robots along plant conveyors: here it must be able to learn to perform only several very similar motions.

Incidentally, this simplicity proved to be deceptive.

"When the tasks that confronted a robot placed at a conveyor were analyzed," states docent I. L. Yerosh, "it was found that it could not manage without image recognition. Let us take, as an example, the Leningrad Porcelain Plant imeni M. V. Lomonosov. Various dishware "float" along the conveyor and among the plates, saucers, and milk pitchers, it is necessary to detect, let us say, only cups, to remove them from the travelling belt, and to place them in containers."

In principle the robot could perform this function. But to recognize cups without error it must have a sharpsighted television eye and quite a high-capacity electronic brain. The use of these expensive automatic "workers" very greatly added to production costs.

To overcome this obstacle it was first decided to build a "sensory surface" -- something like a table completely covered with tactile transducers. On coming onto this surface, each kind of dishware would close a certain number of transducer contacts in a specific combination and the robot would recognize precisely what kind of dishware and in what part of the table it was at a given instant. This markedly facilitates robot operation but other complexities arose: in fact the more numerous the transducers, the more of them malfunction, and the lower the system's reliability. Efforts began to find variants with a minimum number of sensory elements. And unexpectedly the most reasonable idea was thought of (as it now appears to everyone): build transducers in a single line stretching across the conveyor. Dishware will intersect the sensory ruler, switching on at each instant a certain number of transducers. The electronic computer (now a low-capacity model) sums up the signals conveying the successive change of these switchings and will form a dynamic pattern of what is moving along the conveyor. The manipulator will be given a

command with some advance time and the cup will be in its hand.

It is not important what kinds of transducers are used in the alignment. They can be tactile, magnetic, infrared radiation-based, ultrasonic-based... For this specific case -- p[illegible] dishware -- the investigators preferred photocells, arranging them over the conveyor. This solution makes it possible to make the vision of the robot-manipulator more advanced. If, for example, the plane projections which impress against the ruler prove to be inadequate for the robot, a vertical line can also be positioned perpendicular to the horizontal line of transducers. Then the scanning performed in two planes will enable the robot to see three-dimensional images.

The idea of using a sensory ruler at once did away with many complexities: the number of transducers was reduced by several dozens of times; no additional table with a sensory surface was needed; the habitual, long-established conveyor operation regime was maintained, and so on.

Shama the Spider

Attempts to build a traveling automaton were undertaken over roughly 100 years' span -- since P. L. Chebyshev built his "plantigrade mechanism." But thus far no major results were reached in this area. Control of these machines is so complicated that it cannot be executed with purely mechanical means. /20

The first problem that the designer faced was as follows: how many legs should his brainchild be fitted with? Nature offers the richest selection of variants -- from dozens in arthropods to two in man. What should be imitated? Many legs means high stability, and smoothness and uniformity of locomotion. But this

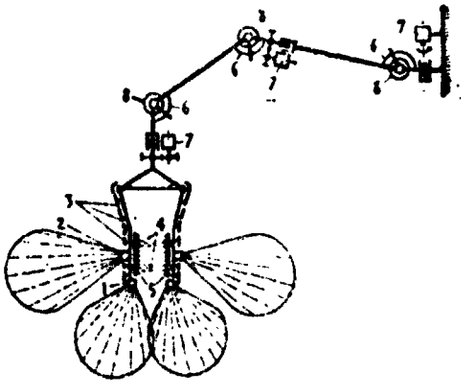
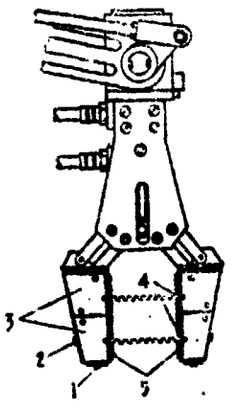


Diagram of the placement of "sensory organs" on the manipulator arm. Photocells 1 and 2 are intended for near-range detection of objects in front of the claw-grab and to either side of it (the hatched zone is the field of view for each of these "eyes"). Two more photometric transducers 4 record the object within the grab. Transducers 5 placed on the inner surface of the claw measure the force of its compression. The outer surface of the claw is covered with a large number of tactile transducers 3 (or with a sensory sleeve) which "sense" the contact by the metal arm with surrounding objects. Potentiometric type instruments 6 and 7 are located in the joints of the arm, determining the angle of rotation of each arm component. Transducers 8 record the forces of the drives -- the hydraulic muscles.

is a mind-boggling problem of coordinating the motion of each support and various other design complexities. Perhaps it is better to have four legs or even two? The mechanism for this kind of system would actually be much simpler. But then one would have to equip the automaton with just as advanced a vestibular apparatus as highly organized animals and man have. And this task until recently was also unfeasible. Only with advances in computers did the possibility of building true machine-walkers appear, machines that in the future would evidently find broad practical uses. And one can make a robot with eight, six, four, or even two legs -- ever[illegible]ng depends on the capacity [illegible] its computer.

An object of special pride for institute specialists is the spider: a six-legged travelling machine, Shama, as it is familiarly called in the laboratory. All its legs are studded with transducers so that data on both the position of the legs in space and on the condition of the surface on which they are moving are continually fed to the robot's brain. A laser eye scans the near-range space and communicates to the



External view of grab equipped with sensors: 1, 2 and 4 are the object-detection photo-transducers; 3 is the sensory sleeve (tactile transducers); 5 are the compression-force transducers.

control device concerning turns in the road and the obstracles if the spider is travelling over broken terrain.

Each leg has three segments, and each of these has its own drive (the spider's legs have a total of 18 degrees of freedom); each leg receives controlling signals via its own channel from the computer. As a result Shama has enormous flexibility in selecting the most varied modes of locomotion. It functions by taking account of the conditions of the road, the soil, and the weight of the load being carried.

Shama can even travel where neither wheeled or tracked mechanisms can go: along corridors that are narrow and have sharp turns, through shops crammed full of equipment, and on ladders. On travelling over broken terrain, across ruts and fallen trees, it changes its gait, and selects the most advantageous approach: it shifts at once first three legs (this is the most rapid pace -- 6 km per hour), then two, and then one, rises on "tiptoes" in order to carry its ' unk over a large rock or squats in order to lengthen its pace and confidently step over a ditch.

If the feet are equipped with special hobs and crampons, Shama can clamber over steep declines and slopes.

We must make special mention of the vision of the travelling machine. The designers rejected a television eye that has been traditional in system of this kind in recent years. A television camera is too awkward, and much time -- up to 10 sec -- is used /21

In the robot laboratory at Leningrad Institute of Aviation Instrument-Building. In the photo (left to right): senior scientific co-worker G. B. Yatsevich, design engineer N. M. Zakharov, and professor M. B. Ignat'yev.

in self-focusing. Finally, for the robot to be able to reliably orient itself with a television eye in the world surrounding it the control electronic computer must have an enormous memory.

All this poorly suited the six-legged spider which was built to move in difficult conditions and which therefore must rapidly detect obstacles, dangers, and with without delay modify its behavior.

The laser eye developed in the radio-vision systems laboratory under the supervision of A. A. Kapustin, G. B. Yatsevich, and V. S. Boykov met these specific requirements much better.

The instrument, by probing space with a narrow infrared beam, distinguishes quite small details to a distance of 10-15 meters; at practically the same time it measures the distance to them with a precision of up to 5 mm.

About 1 sec is used in the detailed -- line by line -- scrutiny of the frame (60-90 degrees in the horizontal and 10 degrees in the vertical). If great carefulness is not required in scanning the locale, the laser sends out a broad beam and scans the space even faster. It continues in this way until the eye detects a new obstacle. Then again the scrutiny of the frame with a narrow beam begins.

Surmounting obstacles by the travelling machine; broad pace and long range of variation in clearance permit the robot to easily pass over ditches, ledges, rocks, and fallen trees.

The first prototype of the helium-neon laser eye (at that time still quite large and awkward) fitted on the Dural back of Shama passed its test. Today a new prototype of the laser eye has been built and it being tested in the laboratory. It is now much more compact, weighs about 4 kg, and sends to the electronic brain the first-communicated data on what has been seen: silhouettes of objects and information on the distance to them. /22

Where then can the six-legged spider find application? This obviously includes carrying light loads within multistory buildings, servicing agricultural and forest tracts, and

participating in geological prospecting teams. These machines can fulfill assignments at the bottom of seas and oceans, on other planets and, of course, in production conditions that are dangerous to man.

Snake on Short Legs?

The six-legged spider S'ama and the metal arm are not yet workers, but guests. Guests from the future. Research on these laboratory models of "intelligent" machines assists in discovering their "capabilities" and in solving several theoretical problems facing robot construction.

Recently a new model of the "iron arm" has begun to be manufactured in metal. The experience gained in the years that have elapsed is taken account of; the disadvantages of the former arm design have been eliminated. This robot is designed so that it can perform the most varied work operations. And to do this one need only change its control program, eye, and claw-grab. For example, in working at a conveyor it is able to both successfully manipulate either a carefully machined part, or a brick, or a cast iron bar.

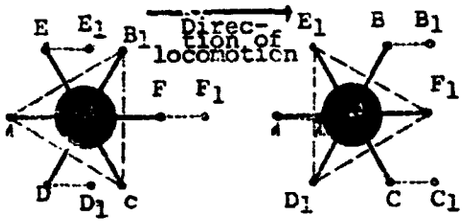
Scientists hope that robots for which this model will be a basis will in the not too distant future become participants in many manufacturing processes.

Many scientific establishments as well as enterprises of our country are now dealing with the problems of building and using electronic helpers of man. Successes in building the simplest manipulators and automata have stimulated work on even more complicated models. In this process more and more new scientific and engineering manpower is being recruited. For example, automatic devices, including robots, must find wide applications

in the shops being designed at the Leningrad Turbine Blade Plant. A prototype of a robot that will be tested in stamping parts has been built in the All-Union Technological-Designing Institute of the Electrotechnical Industry. Under the leadership of V. L. Zhavner at the Leningrad Technological Institute of the Refrigeration Industry, a copying manipulator has been designed. A steel arm controlled by a single operator is capable of picking up a 400 kg load, easily and rapidly transporting it in a narrow space over a distance of 2.5 meters or lifting it to about the same height (with a small amount of reequipping of the machine, the lift height can be changed to 3.5 meters). Today the Leningrad Special Design Bureau of the RSFSR Ministry of the Meat and Dairy Industry is building an industrial prototype of this manipulator. It will drag and stack animal carcasses in refrigerator rooms, load and unload railcars and van trucks.

Interest in robot-manipulators is quite natural. Since remote centuries people have dreamed about such automatic assistants. But efforts to build them encountered insurmountable difficulties. The first serious successes in this endeavor go back to the 1940's-1950's when automatic shops and factories were built. But it was soon found that the enterprises were hard pressed to adapt to the rapid changes in technology, to use other kinds of raw material, and to produce new products when equipped with "rigid" automata, that is, automata that could perform only several quite specific operations. Often this necessitated a radical redesigning of the automatic lines. /23

Advances in science and in electronic technology opened up new possibilities: intensive development of devices for easing mental labor and facilitating automatic production control systems began. And the problem of building machines independently performing repetitious labor operations directly at work stations was shifted to the background.



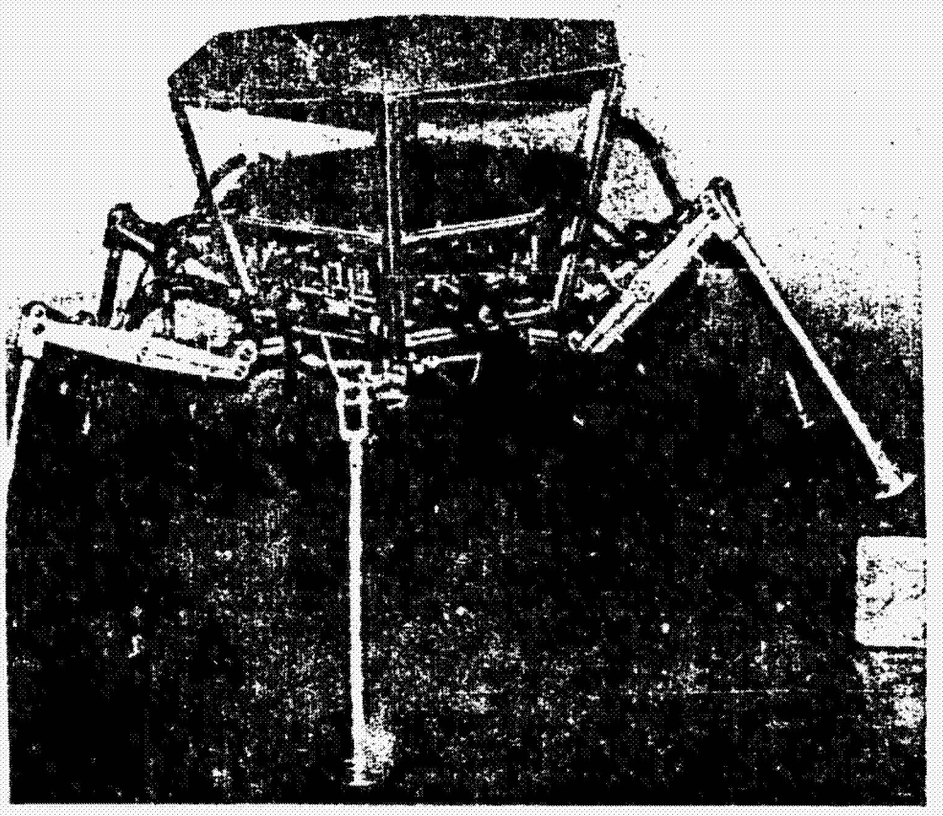
Scheme of motion of the six-legged travelling machine. The variant in which the robot moves on three legs during each motor act is shown: first, supports D, E, F shift to the position D_1, E_1, and F_1, then supports A, B, and C -- to the position A_1, B_1, and C_1. In all positions the center of gravity O is within the support triangle (shown with a dashed line in the scheme), which ensures great stability for the machine. In this scheme, the robot is moving left to right. If each of its legs has no less than three degrees of freedom, the machine can travel in any direction with equal ease. Variant "three legs + + three legs" provides the maximum travel speed; it is preferably used in walking over a locale with shallow grades, hummocks, and depressions.

As a result, a paradoxical situation developed in which relatively highly intellectual human functions were being successfully automated, but not as many devices capable of performing unqualified production operations "with intelligence" exist. Currently a great many people as before are engaged in manual and auxiliary work. To transfer these operations to machines means to bring into play tremendous reserves for raising labor productivity.

Still, the level of advances in science and technology is already such that constructing an entire army of "intelligent" automaton-robots flexibly adapting to continuously changing functions and conditions of production has become a quite realistic endeavor.

"Today were are experiencing a transitional period in the development of production -- the stage of 'robotization' of interprises has begun," states Professor M. B. Ignat'yev. "We must try to have thousands of robots working in 10 to 15 years."

Year by year the robots will "get smarter." And, evidently, this time will soon come when without any special difficulty they can take on themselves the most tiring and uninteresting



One of the first models of traveling robots -- Shama the spider (eye and control unit not installed).

kinds of human activity. Even in the household. Robots are even being designed for the home. They must wash dishes and straighten up rooms, lay tablecloths...

No small number of complicated problems arise in this respect. For example, one such problem is the development of reliable "eyes" and "ears" for robots, and system of communication between them and man. Nor is the following problem a matter of indifference: what appearance must the robot have? In Japan it is believed that an electronic helper in the form of /24
a snake on short legs is the most convenient; British researchers give a preference to devices that look like man. Still to be

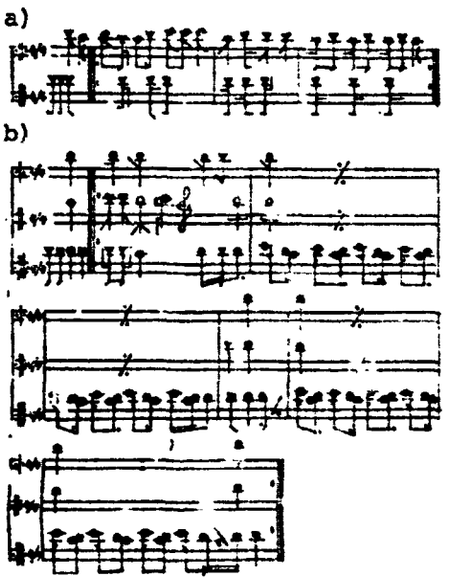
resolved is the question of what kind of temperament must the robot have. Its overcompliance and stubbornness, or sluggishness, or excessive agility can irritate the person that must work with them at the plant or home. Obviously, both psychologists and sociologists must labor over this.

Assigning to automata-manipulators the main kinds of auxiliary, conveyor, loading-unloading, and housework, as well as several purposeful work operations in outer space and in the ocean will signal the end of the present, first stage of "robotization." In the second stage robots with artificial intellect which can without much exaggeration be called intelligent will find applications.

In Their Own Image and Likeness

The main feature of robots of the present day is that a model of the external world must necessarily be placed in their memory storage, formulated by man or else formed by the artificial intellect as the result of the independent accumulation of information about the real external environment. This gives rise to a situation in which the robot will function not only according to a written program placed in its memory and not only by the trial and error method. It can act like man: before beginning any steps, it simulates its activity, plans it, taking account of the characteristics of its environment and the goals it aims at.

All this, state the institute scientists, will be of enormous value, especially in conditions when a large number of automata-intellectuals will begin to work at plants and when the inevitable problem of controlling their collective will face personnel.

The problem is that in production robots will evidently be most efficiently and profitably used in large groups (of 10 to 100

Motography is a system for recording human motions developed by Murmansk physician A. P. Valyshev, and it resembles musical notation and is a little more complicated than it. In it five main symbols and several dozens of auxiliary symbols are used. Motographic terms either coincide with musical (accidentals, clefs, naturals, intervals), or are comparable with them: note -- motion; sound -- movement; tone -- gesture; semitone -- semigesture; harmony -- motory, and sharp -- + change. In motograms, a -- recording of the work of a bricklayer; b -- recording of the movements of a stevedore carrying a sack.

Legend of auxiliary signs:

- – Brick
- – Plastering trowel
- – Mortar
- – Sack containing load
- – Position of load at initial platform
- . Position of load at final platform

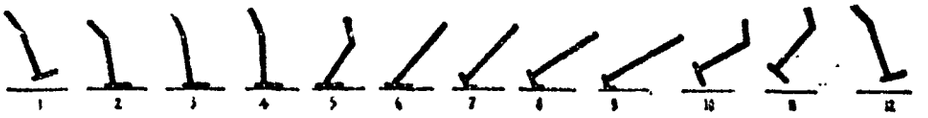
each) and in a complex with other modern equipment -- automated warehouses, programmed-control machine tools, etc. General supervision of all these devices can be assigned to a single electronic computer. But still a certain independence will have to be preserved for the robots -- from considerations of flexibility in their actions. And now a number of scientific problems will arise. Let us say, how must robots arrange their relationships with each other? How can the division of labor between them be ensured, on the one hand, and on the other -- their ability to help each other? The problem is how can they jointly move along a heavy load, perform complicated /25 work where many hands are required, replace a malfunctioned manipulator and remove a hazard from a neighbor. Who must effectively supervise the

"collective" of automata -- a robot of higher rank, let us say a robot-chief, or a man?

It is not easy to effectively resolve these problems. It is highly probable that the "self-awareness of a robot will have to be resorted to for assistance, that is, its ability to construct its own model (the model of its "I"), to place it in the model of the external world formulated in its memory and to analyze how its future behavior will "appear" "in the eyes" of the other members of the "collective" of automata, as well as the eyes of the manager. If all this will prove accessible to the robot, if he before beginning to make a decision on how to act in a given situation will consider the social opinion and the "collective" of robots, in a word, if he will be guided by categories (or identical) to our, human categories of morality and ethics, then no insoluble problems will arise in managing interrelationships of intelligent automata with each other and with man.

Similar tasks, believes Professor M. B. Ignat'yev, will arise in full measure in the near future. Therefore, even today one must prepare for their solution. And this necessitates the joint efforts of specialists in the most diverse profiles. In order to obtain an answer to many problems associated with the behavior of robots, one will have to resort to sciences that are extremely removed from those which are now engaged in building and improving artificial intellect. Here are several examples accumulated already by robot technology itself.

At one time attempts to set up for manipulators programs simulating actions of the human body during work operations encountered an apparently insurmountable complexity and the indescribable diversity of these motions. It is obvious that this was explained by the fact that in spite of the long-standing efforts of people to devise a "language of motions" similar to written language or musical notation, they were unsuccessful. It is for



Phases of human foot motion as viewed by robot instructors.

this reason that many folk and ritual dances and works of art -- ballets and pantomimes -- have proved to be irretrievably lost.

When programmers delved deeper into the theoretical and technical problems of ballet, they found that somethingsimilar to what they needed had already been devised, for example, kinetography is a special language of the shorthand type (it was developed by British choreographer R. Laban) that permits recording of the static position of the human body and the dynamics of its motion and even mimicry.

Incidentally, not only choreography but also medicine came to the assistance of the robot-builders. Murmansk physician A. P. Valyshev devised a "motion grammar," or motography -- a system for the precise recording of the motions of the human body at work.

Study of the developments of R. Laban and A. P. Valyshev convinced specialists that by constructing translators to convert these graphic languages into the language of the computer descriptions of any human motions could be fed directly into the robot brain, and they would serve as a program for the robot.

A similar situation developed also in attempts to formulate scenarios of behavior for higher-rank robots. True, nothing ready made was found. But as it turned out, some basis for resolving the highly complex behavior problems still already is available. And it was devised by philologists and literature specialists.

As early as 1928 the famed folklorist, Professor V. Ya. Propp of Leningrad University wrote the book Morfologiya Skazki [Morphology of the Folk Tale]. Today it is being most closely studied by many engineers and mathematicians -- robot builders. The point is that V. Ya. Propp analyzed an enormous number of folk tales and isolated 31 typical elements of behavior of the characters. It turned out that all the folk tales of the world were constructed using these elements. These studies are a most valuable body of material for the development of the character, behavior, and world view of robots of tomorrow.

"Today," states Professor M. B. Ignat'yev, "we have concluded agreements with the literature specialists (primarily at Tartu University where these studies have been successfully developed), are financing their investigations, and expect that we will get recommendations and conclusions that are very necessary to science. In order to consolidate the collaboration between the philologists and engineers, to achieve better mutual understanding, and to formulate common problems, we intend to hold a joint symposium on the problem's algorithmizations of the external behavior of systems of the robot-manipulator type." This is the first step of its kind. In our view, a new field of science is taking shape, which can be called -- on analogy with bionics -- artonics. but whereas bionics assists in finding from nature answers to relatively simple engineering problems artonics must, by investigating art (in the broad sense of this work), suggest to engineers solutions to much more complicated problems.

... When we left the robot laboratory at Leningrad Institute of Aviation Instrument-Building, the metal spider stood in the middle of the room in its alert pose, apparently ready with all its six feet to rush to perform the command of man, and the automatic arm lowered its heavy claw on its dural back, as if quieting it. I knew that today this was a chance pose and was not

at all a meaningful gesture. But soon robots will actually be not only industrious and efficient, but also attentive, tactful, and kind toward each other and toward man -- these are the qualities that people will teach them.

The robot is beginning its ascent on the ladder of evolution...